



**Department of Surgical Sciences  
University of Bergen**

**A 3-D post-mortem model provides rationale for  
complications in gastrointestinal surgery**

-A post-mortem corrosion-cast model-

**by**

**Dejan Ignjatovic**

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When MIS was introduced into my professional life I was confronted with many of the frustrations surgeons usually experience while learning to master a new technique. Looking for solutions a combination of anatomical studies with surgical experience seemed natural. While on this quest I ended up in Norway, and destiny provided family, friends and a new perspective.

The views presented in this thesis are the result of this *new* perspective.

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**Abbreviations:**

MIS	Minimally invasive surgery
2-D	Two dimensional
3-D	Three dimensional
GTH	Gastrocolic trunk of Henle
SMV	Superior mesenteric vein
ICA	Ileocolic artery
RCA	Right colic artery
CT	Computer tomography
MRI	Magnetic resonance imaging
CBD	Common bile duct
ERCP	Endoscopic retrograde cholangio pancreatography
NSAID	Non steroid anti inflammatory drug

## **List of original papers**

This thesis is based on the following original papers:

**I.** Bergamaschi R, Ignjatovic D. More than two structures in Calot's triangle. A postmortem study. **Surg Endosc.** 2000 Apr;14(4):354-7

**II.** Bergamaschi R, Ignjatovic D. Anatomic rationale for arterial bleeding from the liver bed during and/or after laparoscopic cholecystectomy: a postmortem study. **Surg Laparosc Endosc Percutan Tech.** 1999 Aug;9(4):267-70

**III.** Ignjatovic D, Bergamaschi R. Anatomical rationale for spleen salvage by lobe/segment dearterialization in inferior pole spleen injury during left hemicolectomy: a post-mortem study. **Tech Coloproctol.** 2002 Sep;6(2):93-5

**IV.** Ignjatovic D, Stimec B, Zivanovic V. The basis for splenic segmental dearterialization: a post-mortem study. **Surg Radiol Anat.** 2005 Mar;27(1):15-8

**V.** Ignjatovic D, Stimec B, Finjord T, Bergamaschi R. Venous anatomy of the right colon: three-dimensional topographic mapping of the gastrocolic trunk of Henle. **Tech Coloproctol.** 2004 Mar;8(1):19-21

**VI.** Ignjatovic D, Sund S, Stimec B, Bergamaschi R. Vascular constraints in right colectomy for cancer. Clinical implications. **Submitted**

## **1. Introduction**

There are several obvious advantages of minimally invasive surgery (MIS) which make it attractive to patients, surgeons, and hospitals. These advantages are: minimal pain and disability, decreased postoperative ileus and analgesic requirements, less blood loss, reduced stress because of diminished surgical trauma, less impaired respiratory function, earlier resumption of dietary intake, less immuno-suppression and more rapid postoperative recovery, less scarring, shortened hospital stays, less incidence of adhesions and incisional hernia and earlier return to usual activity. After the introduction of laparoscopic cholecystectomy, increased surgical experience and technical innovations have extended the indications to other areas of gastrointestinal surgery. Conversely, many authors have cautioned about higher complication rates, especially during the learning curve.

The reason for the occurrence of specific surgical complications that occur due to the change of access in MIS can be better understood after the analysis of the crucial scientific innovations and the advances of technology that have made the development of MIS possible.

### **1.1. The evolution of MIS**

The first of these innovations was the development of the electric light bulb and lens system by Thomas Edison in 1880 (1), through which illumination of the surgical field was improved. Newman of Glasgow built a miniature version of Edison's light bulb into a cystoscope only four years after its construction (2). Maximilian Nitze (1879) was the first to construct an endoscopic instrument using a lens system that provided a sharper picture with magnification (3). George Kelling was the first to report laparoscopy on dogs with the use of a cystoscope in 1901 and humans in 1923 (4). His experiences were used by the Swedish surgeon H.C. Jacobaeus from Stockholm in 1911 to perform the first thoracoscopy on humans (5).



The second wave of discovery was the development of a rod-lens system by the Englishman Harold H. Hopkins in 1950, together with the development of fiber optic transmission of cold light (1, 6). Prior to this development, endoscopes were constructed on an optical system that was made of glass lenses with long intervening air spaces. This new system interchanged the roles of glass and air, so that the optical system consists of air lenses and long glass spaces, making the refractive index predominantly that of glass, thus doubling the light-transmitting capacity of the endoscope. The second advantage of this rod-lens system is a high quality picture. It minimizes light reflection on the inner surface of the lens, which in turn leads to preservation of the contrast in the final image. This in turn leads to a significantly larger, clearer picture.

These technological advances allowed the transmission of a good quality picture, without heating the tissues. However, the equipment was still too large and too heavy to perform MIS procedures. Therefore, laparoscopy was still considered a diagnostic procedure, or used for simple therapeutic procedures only (puncture of ovarian cysts etc.).

The third wave of discovery was the development of the computer-chip video camera (1985) (7). This camera captures the signal from the laparoscope and transmits it as an electrical impulse to a monitor and is small enough to be used in MIS. Prior to the development of this camera, laparoscopic visualization of the abdominal cavity was restricted to the individual directing the operative procedure, while the participation of other members of the surgical team was limited. The inability of the assistant(s) to actively interact with the surgeon rendered complicated operative procedures to be in the least tedious despite the use of articulated attachments. These proved to be cumbersome and ineffective. In 1985, this problem was solved with the development of a computer chip television camera attached to the laparoscope. This was the missing link that allowed the step from diagnostic to therapeutic procedures in MIS.

The procedure that symbolizes this step is the first MIS cholecystectomy performed in Lyon, France in 1987 by Phillippe Mouret, a French gynecologist (7).

## **1.2. The challenges of MIS**

These scientific innovations created MIS in its modern version. During this development a completely new terminology became part of the surgeon's vocabulary, including the following expressions: the fulcrum effect, 2-D environment, video controlled environment, paradoxical hand-eye movement, hand-eye dissociation, long distance surgery, tactile perception, haptic perception/feedback, instruments with limited degrees of motion freedom etc (9, 10). This terminology was devised in order to define problems encountered while learning and performing MIS.

Surgical training has traditionally been hands-on learning, the experienced surgeon instructing the novice on how to perform the procedure. MIS has created an obstacle to the traditional teaching model. Trainee surgeons can no longer easily mimic their mentors' actions. It has become apparent that MIS, today, requires at least two unique skill sets, these being psychomotor and perceptual skills (10, 11). Psychomotor skills can be acquired through the use of MIS physical or virtual simulators (10, 12), thereby ensuring that inadvertent lesions to nearby organs and structures are avoided. However, as opposed to psychomotor skills, the lack of perceptual skills is what causes conscious and willful lesions to anatomical structures contributing to the increase in complication rates during and/or after MIS procedures (13-20). A surgeon is required to identify the anatomy while operating prior to the division of anatomical structures. Willful, conscious lesions are defined as non-malicious lesions that occur after the decision on the anatomy has been made, as opposed to those made without such a decision. This problem has also been observed and discussed in Scandinavian countries (21-24). It must be realized that the surgeon is dependent on a screen during the procedure,

which is in essence a 2-D picture. The absence of depth in this 2-D picture makes spatial relations of anatomical structures difficult to identify. The laparoscopic surgeon has to find a way to guide his or her maneuvers in a 3-D environment by watching a 2-D screen (25). In other words, the operator loses the depth cue of binocularity and has to compensate with other depth cues.

These drawbacks are not present in open surgery.

### **1.3. Complications in MIS**

A rise in the number of surgical complications after the introduction of MIS is well documented in the literature (13-20). Most of these are described in gallbladder surgery; the most frequent and first performed laparoscopic procedure throughout the world, with 750000 procedures per year in the USA (26). However, this increase of complication rates with laparoscopic access was not so easy to prove in other segments of gastro-intestinal surgery (27, 28). The reasons for this could be the division between complications and conversion, underreporting of complications due to MIS (port site hernia, small bowel perforations etc) or the well documented lower incidence of minor complications (29).

Establishing the cause of surgical complications is neither simple nor easy, but is of paramount importance in the prevention of future repetition. One of the benefits of MIS is that it provides a video recording of the procedure that can be analyzed after the complication occurs, but this is often inadequate in giving an anatomical rationale for surgical complications because in essence it is a 2-D picture. Thus, the cause of the complication may remain unresolved unless the patient is re-operated. Paradoxically, its cause often remains unclear even after re-operation. Intra-abdominal bleedings are expansive and are often self-controlled due to the compression of the growing blood clot, and at surgery one finds large blood clots without finding the blood vessel responsible. In infection, collections of puss or

bile also modify the anatomy. Therefore, the collection of more data as well as supplementary techniques is necessary to identify the major pitfalls leading to surgical complications in MIS.

#### **1.4. Anatomy studies**

Anatomy is the cornerstone of any surgical procedure, and a thorough knowledge of anatomic features can reduce operative mistakes and complications, even more so in MIS. A medical student's first contact with anatomy is based on 2-D drawings and photographs in anatomy books and atlases. On the other hand, practical anatomy is taught on bodies preserved with formaldehyde. Such cadavers provide altered 3-D anatomical relations due to dehydration and shrinkage of tissues. Furthermore, these cadavers are prepared for presentation through the removal of connective tissue between individual anatomical structures. This, in turn, allows movement of elements for several millimeters or centimeters from their original position, thus disrupting the original 3-D mutual relations. Finally, anatomy courses can be organized on fresh human cadavers. The use of fresh human cadavers has several limitations, such as ethical issues, rigor mortis, collapsed blood vessels and no bleeding.

Because of all these factors we can say that the way we learn anatomy can be misleading for MIS surgeons that operate on 3-D anatomy. The way we learn anatomy can also be a reason for prolonged learning curves and higher complication rates (30).

#### **1.5. The corrosion cast**

The advantage of corrosion casting is that it provides us with a physical 3-D anatomy model. This model shows relations of full vessels in fresh cadaver tissues, without the presence of the tissue itself. Corrosion casting is used to produce scientifically exact, multi-colored specimens for anatomical study, comparative demonstrations and even for quantitative scanning electron microscopy studies. The method was developed about 70 years ago, when the so-called

polymeric science succeeded in producing synthetic materials and made them available to industrial manufacturing. It was August Schummer, former Professor of Veterinary Anatomy at the University of Giessen, Germany, who recognized the use of these new materials for corrosion casting anatomy (8). Through the employment of this method, which was named after him, an epoch-making step was achieved in the study of anatomy. Thus, from the corrosion cast model exact measurements of anatomical structures can be made, and their spatial relations estimated.

This technique can, together with radiographic procedures performed *post mortem* (arteriography, cholangiography) (31, 32), provide valuable anatomical information that can in turn improve the understanding of complications in gastro-intestinal surgery. In some cases this knowledge can even suggest improvements of procedures.

## **2. Aims of the study**

The aim of the study was to develop 3-D anatomical models that can shed light on the basis for some surgical complications that occur after MIS procedures. The study consists of the following main parts:

1. Anatomical considerations in complications during and/or after MIS cholecystectomy.  
The aim is to provide a rationale for arterial bleeding from the liver bed, and anatomical data for the correct handling of more than two structures within the Calot's triangle.
2. Anatomical considerations after spleen injury during left colectomy. The aim is to determine the rationale for spleen salvage by lobe/segment de-arterialization for lower pole injury and to define and quantify the segmental vessels of the splenic hilum.
3. Anatomical considerations in vascular complications during and/or after right colectomy for cancer. The aim is to define the calibre, length and three-dimensional

position of the gastrocolic trunk of Henle and accurately define relations between the superior mesenteric vein and the right colic and ileocolic arteries.

### **3. Material and methods**

#### **3.1. Study design**

Research specimens were obtained from cadavers during the post-mortem examination. The specimens in Serbia were obtained according to the Law on Medical Care, Section IX, articles 215-223 on the procurement of bodies and organs of deceased persons for education and scientific studies at the University. In Norway, regional ethical committee approval was obtained prior to the start of the study (REK Vest nr.156.04). Specimens were harvested according to the post-mortem investigation law (article 542 from 19. march 2004), providing there were no reservations to research from the next of kin.

All the studies were case-series. The methods employed were corrosion casting, post-mortem arteriography, post-mortem cholangiography and anatomical dissection. Statistics were descriptive. Sample size calculations were based on data from available literature.

#### **3.2. Corrosion casting**

Specimens were obtained from cadavers from the Institute for Forensic medicine, Belgrade, Serbia and the Department of pathology of Førde Central Hospital, Førde, Norway. Organs were removed *en block* together with surrounding organs in order to preserve the anatomical elements. There were three different areas within the abdomen of surgical interest, and therefore three types of specimens. Description can be found within the individual articles. Specimens that were damaged or contained pathology that could alter the anatomical relations (tumors, cysts, anomalies etc.) were excluded from the study. After removal the specimen was immediately immersed in 0.9% saline solution at 37° C.

Corrosion casting was carried out through the placement of a 10-French polyethylene catheter into the arteries, veins and/or bile ducts of the specimen. This catheter was fixed to the vessel with a suture, and irrigation with 0.9% saline solution was performed to wash out any retained coagulum and/or sludge. The lateral branches of the vessels were identified while irrigating and ligated to prevent leakage of cold-polymerising methylacrylate during injection.

Different colors were used to inject different vessels. During injection of cold polymerizing methyl acrylate through the catheters, the specimens were immersed in water in order to regain their original shape. Following methyl-acrylate solidification, corrosion by accelerated saponification was then performed in a heated 35% potassium hydroxide solution. Any remnants of organic tissue were washed out with warm water and the casts mounted on stands. Size and length of arteries, veins, and bile ducts were measured by a nonius scalable ruler and flexible copper wire, respectively. If the location of a structure was deep, surrounding vessels were shaved off to allow approach for measuring.

The material consists of partially polymerized monomer, a catalyst, and a promoter (Meliodent Rapid Repair Liquid®, Meliodent Rapid Repair Powder®) to allow solidification at room temperature after injection. Pigments/acrylate colors are used for contrast.

Plastic models are tough and durable but not with the ability to be handled without fear of damage. It is necessary to prepare all anatomical specimens prior to mixing the ingredients. Polymerization begins very quickly after the mixture is completed. The solidification time of the mixture can be varied by adding more or less of the components. The optimum technique is to take the liquid component first, add the pigment, and then add the powder component. Stir vigorously with a spatula until mixed.

In order to obtain a good model the following tips are crucial. The specimen must be harvested wide enough to include as many as possible lateral branches of the vessel being studied. All lateral branches must be ligated, otherwise the leakage of methyl acrylate will not

allow good and complete filling of all branches. Methyl acrylate injection should be under constant pressure and with the use of only one large enough syringe. The specimen should be allowed to freely swim in water during injection; one side of it will be completely flat if the specimen is injected on a table, thus disrupting anatomical relations. The specimen should not be moved, and the same water should then be used for corrosion by adding potassium hydroxide into it. Moving the specimen while organic tissue is present leads to its damage. Higher temperatures and continuous heating accelerate corrosion, thus at an optimal temperature of 45°C a model can be free from organic tissue within 24 hrs. This lowers the risk of damage to the model. Rinsing the specimen should also be done with hot water and patience while rinsing is most important.

### **3.3. Postmortem arteriography and cholangiography**

The organs are removed from the cadaver as described above. The vessels being studied were prepared and a 10-French polyethylene catheter placed and sutured to it. Irrigation with saline solution was performed in order to remove blood clots/sludge from the vessel. Ligation of collateral vessels was carried out during irrigation, saline leakage visualizes their location. Barium sulfate suspension was injected through the catheter under constant pressure and the injection of contrast was monitored by radioscopy. Once radioscopy showed complete filling of the vessels, and resistance was encountered during injection, x-rays were taken. It is important to take x-rays in this precise moment in order to evade blurring of the radiographies due to parenchymal opacification in the specimen. The injection process was visually followed on radioscopy to assess the filling of vessels, but it also provided important data on the existence of communications between the individual vessels and/or their branches. A metallic etalon was used during radiography for comparative measurements.



After the performed postmortem arteriography blood vessels were anatomically dissected. Special attention was devoted to the hepatic artery and its terminal branches, the cystic artery, the splenic artery and its terminal branches as well as the segmental splenic arteries. Arteries filled with barium suspension are colored white and are easy to notice. The results obtained by anatomical dissection were later compared to the post-mortem arteriographies in order to achieve a better description of the blood vessels.

Post-mortem cholangiography was performed in a similar manner. The procedure was simpler due to the fact that the bile ducts do not have collateral branches. The cystic duct was not ligated when performing post-mortem cholangiography. A gallbladder filled with barium sulphate did not impair the visibility of the bile ducts or arteries. Radiography was performed in an identical manner as the post-mortem arteriographies, and a metal etalon was used for comparative measurements.

#### **4. Summary of findings**

##### **Paper 1.**

The study was designed to provide correct 3-D anatomical data critical to surgeons faced with more than two structures within Calot's triangle, and to provide an anatomical rationale for intra-operative bleedings and bile duct injuries during and/or after laparoscopic cholecystectomy.

Third structures within Calot's triangle were arteries (0.6-5.7 mm diameter) in 36.2% (early division of the right hepatic artery, 8.6%; caterpillar hump right hepatic artery, 12.9%; liver branch of the cystic artery, 10%; double cystic arteries, 5.7%), bile ducts (0.3-1.6 mm diameter) in 5.7% (small-caliber sectoral ducts, 1.4%; right posterior hepatic ducts, 4.3%), and veins (0.9-1.6 mm diameter) merging with the portal vein in 4% of the specimens.

## **Paper 2.**

The aim of this study was to establish an anatomic rationale for liver bed arterial bleeding during and/or after laparoscopic cholecystectomy. The same study models were used as in paper 1, excluding the post-mortem arteriographies and cholangiographies.

Six anastomotic branches (12%) of the cystic artery to the right or left hepatic artery ran underneath the gallbladder serosa surface and entered liver parenchyma after crossing the medial or lateral edge of the liver fossa without passing through the areolar tissue of the liver bed. Their mean length was 18.3 mm (range 4-60), and the mean diameter was 0.38 mm (range 0.2-0.8). Two cystic arteries that ascended in the midline between the gallbladder and liver bed were identified in 50 (4%) casts. Their lengths were 16 and 18 mm, and their diameters were 1.9 and 2.2 mm. Five and seven branches encircling the gallbladder arose radially.

## **Paper 3.**

The aim of this study was to determine the rationale for spleen salvage by lobe/segment dearterialization without resection for inferior pole injury during left hemicolectomy.

The mean inferior terminal splenic artery had a significantly smaller diameter than the superior (2.8 vs. 3.4 mm,  $p < 0.01$ ). An inferior polar artery was found in 22.5% of the specimens (mean diameter, 1.9 mm; mean length, 33 mm). The inferior lobe and inferior polar segment comprised 41.3% and 12.6% of the spleen, respectively. Anastomoses were detected in 34 of 102 spleens (3% extraparenchymal, 88% intraparenchymal, 9% combined). The mean diameter and length of intrasplenic anastomoses were 0.3 mm and 20 mm, respectively.

#### **Paper 4.**

The goal of this study was to thoroughly investigate the 3-D anatomical features of the splenic segmental vessels with a view to surgical applications. The same study models were used as in paper 3.

The superior terminal splenic branch divided extracapsularly into  $2.8 \pm 0.9$  (range 2-5) and the inferior terminal splenic branch into  $2.3 \pm 0.75$  (range 2-5) branches per sample. The extracapsular lengths of the segmental branches ranged from 4.0 to 16.7 mm and the calibers from 0.4 to 2.2 mm. Superior polar arteries occurred in 31.3% and inferior polar arteries in 20.6% of cases. Their average extracapsular lengths were 39 mm and 31 mm, respectively. In conclusion, segmental splenic arteries have an extrasplenic origin and course, with an average length and caliber that allow surgical access and ligation, in order to achieve segmental dearterialization for hemostasis purposes and splenic preservation.

#### **Paper 5.**

The aim of this study was to define the caliber, length and three-dimensional position of the GTH in context to right colectomy.

The GTH was present in all specimens originating from the confluence of the right gastroepiploic and superior-anterior pancreaticoduodenal veins. The GTH joined the SMV at an average distance of 2.2 cm (range, 1.6-3.2 cm) from the inferior pancreatic border and it coursed towards the right side in a ventral-cranial direction. The mean caliber and length of the GTH were 5.2 mm (range, 4.8-5.8 mm) and 16.1 mm (range, 10.1-20.7 mm), respectively.

#### **Paper 6.**

The study aim was to provide 3-D anatomical data on pattern and length of crossing of the ICA and RCA with the SMV in context to right colectomy for cancer.

ICA was present in all specimens crossing posterior to SMV in 19/30 specimens (63.33%). Length of crossing was  $17.01 \pm 7.84$  (7.09-42.89) mm. RCA was present in 19/30 specimens (63.33%). RCA crossed anterior to SMV in 16/19 specimens (84.21%). Length of crossing was  $20.63 \pm 8.09$  (6.3-35.7) mm.

## **5. Discussion**

### **5.1. Cognitive psychology and surgical complications**

Prior to the discussion of individual complications during/after MIS, insight should be provided into the cognitive psychological aspects of human error (33–39). As previously stated, at least two sets of skills are needed in MIS: cognitive skills (why willful lesions of anatomical structures occur) and psychomotor skills (why accidental lesions of anatomical structures occur). Analyses of inadvertent events in high risk industries (e.g. MIS) show that they are predominantly result from misperception (cognitive), and not from lack of knowledge or deficiency of manual skill (35, 40–43).

The general features of human cognition (35, 44, 45) can be applied to the cognitive processes involved in performing MIS. Perception provides information on the target tissue. The operative plan and procedural skills are stored in the long-term memory. Information acquired through the senses is first processed at a subconscious level, and conscious thinking makes decisions and directs the actions that result in a surgical procedure. Complications occur due to error at any point in this sequence. The process is based on heuristics. Heuristic processes are mental procedures that solve problems by making use of uncertain, probabilistic information (35, 44–47). They are normal, quick and effective decision making algorithms. They are, however, not conscious algorithms thus not always providing the correct solution. Visual illusions (39, 41, 46, 48, 49) demonstrate how perception can be faulty and beyond the

surgeon's knowledge or control (37, 46, 50), thereby being crucial to the mechanism of causing complications. When surgeons inspect the target tissue and surrounding structures to identify the anatomy, the subconscious brain seeks a pattern to match the mental model stored in long-term memory. This long-term memory pattern is dependent on how the previous anatomical knowledge was acquired. The anatomy at hand, however, is not completely clear. The borders are not clean and uninterrupted and are partially obscured by connective tissue, inflammation, or blood. Thus, a combination of signals and noise compared to stored anatomical data results in a decision. When enough of the anatomy is visible, subconscious decisions are made concerning form (39, 41, 46, 48, 49). Being subconscious, the processes of thought are not available to introspective analysis, and unless contradictory findings are detected and acted on, a decision is made that the anatomy has been identified. This process is also susceptible to shortening in situations that require hasty decisions (e.g. bleeding), therefore having a higher risk for error.

The fact that complications occurring within/after MIS clearly differ from those occurring within/after open surgery (e.g. bile duct injury) implies that something in the MIS environment predisposes misperception in a different way than it does in open surgery (30). This entails that the heuristics adopted in open surgery do not, and cannot apply in the MIS environment. What is unique to MIS is the loss of 3-D vision and haptic perception. Haptic perception is a complex process described as active touch as opposed to passive touch. (51, 52) and is of great help in establishing the 3-D position of anatomical elements in open surgery. Manual examination of the tissues can give data on size, shape, texture, hardness, borders, and mobility, as well as depth, thus constituting a form of visualization. Experimental data have shown that the visual cortex is among the higher centers involved in processing the information. In the MIS environment, the visual system alone implicitly makes assumptions about the anatomy as it analyzes the 2-D imaging information being processed on its way

towards the conscious mind. This process is dependent on the quality of previously assimilated data, which is in turn dependent on the quality of the process of assimilation. This heuristic problem leads to a tendency to err in the direction of “the familiar and the expected.” The fact that “the familiar and expected” are based on the anatomy studied for open surgery and/or derived from open surgery situations (where both haptics and 3-D view are available) is relevant to the mechanism of MIS complications. Furthermore, human decision-making is influenced by what is called “confirmation bias” (44, 45, 53, 54). Once the judgment has been made, the surgeon has a tendency to discount the significance of newly acquired contradictory evidence in favor of the initial decision. This is not a character defect, because cognitive biases are integral features of human reasoning.

In order to achieve results one must tackle the origin of these misconceptions that result in complications. The experiences obtained from other high-risk industries have shown disappointing and transient influences of additional training on performance failures that originate in the heuristics and biases of the human mind (33, 44). Answers should rather be sought in system changes and not the individual surgeon (33, 36, 38, 40, 55, 56). Within the context of complications during/after MIS, process change might entail a change in the way anatomical knowledge is acquired, or perhaps a change in conduct of the operation. When the latter is concerned several innovations have been proposed such as illumination of the CBD through the introduction of an optic fiber via a duodenoscope during the operative procedure (57), new retraction techniques (58), laparoscopic analogues to anterograde cholecystectomy in open surgery (59), development of laparoscopic ultrasonic Doppler instruments that facilitate intra-operative detection of blood vessels (25) etc. On the other hand, preoperative preparation has been brought further with old (60) and new investigation methods such as multidetector 3-D CT using drip infusion cholangiography (61) or spiral CT (62) as well as their use in the development of a 3-D navigator for laparoscopic surgery (63, 64). The result

of the MIS surgeon's frustration is manifested in new terminology such as "the hidden cystic duct syndrome" or "the false infundibulum" which should, in turn, provide an explanation for complications (65). However, all these articles provide a basis for the opinion that cognitive skills are those that determine the occurrence of willful lesions to anatomical structures during laparoscopic surgery. Anomalous anatomy is important but it is not the sole cause for complications. The cause of these is rather the misidentification of the anatomy (66).

## **5.2. The corrosion cast anatomical model**

As mentioned in the introduction, it is now 70 years since the corrosion cast model was introduced in anatomical studies (8). The model has been developed and improved continuously with the introduction of finer materials, providing the opportunity to influence solidification time and viscosity of the acrylate. The model was, however, burdened with a very long period of time needed to perform corrosion (depending on size of the specimen up to 2 weeks), subsequently needing frequent rinsing of the specimen. Rinsing and change of the potassium hydroxide solution requires handling of the specimen while organic tissue is still present. This leads to its damage, often rendering it useless to the study. Acceleration of saponification through the heating of the potassium hydroxide solution represents a significant shortening of the time interval (up to 24 hours) and does not require rinsing of the specimen. The specimen is thus retrieved without any organic tissue on it and free of damage. According to our knowledge, our method of accelerated saponification is novel and previously not reported in the literature.

## **5.3. Anatomical considerations in complications during/after MIS cholecystectomy**

During the 70s and 80s of the last century it was widely accepted that anatomical knowledge of this region was perfected through the works of Michels and Hollinshead (67-69). However,

after the introduction of MIS cholecystectomy in the late 80s and early 90s anatomical studies of the region became once again interesting, resulting in a substantial number of articles published (70-79), because of the rise in complication rates when compared to open cholecystectomy (13-20, 26, 30, 80-82). In the early years this increase was attributed to the inexperience of individual surgeons with the new technique, the “learning curve” (14). However, despite expectations that these rates would decrease over time, a deeper analysis of the data has shown that the level of complication rates after MIS cholecystectomy have, after an initial fall, reached a plateau which seems to be three to fourfold higher than that after open cholecystectomy (13, 16, 17, 19, 20, 30, 80, 81). Results from open cholecystectomy indicate that CBD injuries occur in 0,1-0.2% patients, while results from laparoscopic procedures indicate that the plateau is reached and is between 0.2-0.8% (17, 19, 20, 80,81) but can go as high as 2.7% (81). These high complication rates cannot be explained by the learning curve (20, 30). Variant anatomy of the region has been accused (14, 17, 65, 73-80), but we cannot ignore the fact that surgeons that perform open cholecystectomy are confronted with the same anatomy. When the severity of lesions to the CBD is taken under consideration, MIS injuries seem to be more severe and, on average more central to the liver (20, 30, 83). This increase of complication rates and their different nature is rather a result of the changed mode of access. Postoperative bile leaks, subhepatic bile collections and bile peritonitis are caused by biliary tract lesions, that are, in turn, according to proposed classifications divided into 4 to 5 groups depending on time of onset and severity of symptoms (18, 20, 65, 83). A difference is made between “minor” and “major” bile duct lesions. Minor bile duct lesions occur in 0.3-2.1% (17, 18), and are caused by lesion of bile ducts that are not in continuity with the main bile duct system, poor clip placement on the cystic duct stump or laceration and cautery of the extrahepatic bile ducts (14, 17, 18, 20, 75). Poor clip placement and laceration of the common hepatic duct are technical issues, while lesions of ducts that are not in continuity with the



main bile duct system are an anatomical and cognitive issue. Our results provide data on the contents of Calot's triangle, showing that sectoral bile ducts occur in 5.7% of specimens and have a course that is parallel to the CBD, whether they end in the CBD itself or the cystic duct. Their origin is most often from the posterior segment of the right liver lobe, not communicating with the main duct system other than through this duct. The operative technique deployed during MIS cholecystectomy presumes limited dissection close to the gallbladder wall, this being the reason that these ducts are underreported in the literature, and that they are reported only when they are injured (66, 80). As to today, only ten cases of the right hepatic duct entering the cystic duct have been reported (79). The methodology used in our study did not allow the identification of small bile ducts emptying directly into the gallbladder (bile ducts of Luschka), this being the reason that no results are presented. The clinical implications of the 3-D anatomy show that sectoral bile ducts have a parallel course to the CBD and enter the CBD or the cystic duct at an acute angle. The cystic artery/arteries most often pass anterior to this structure (under the peritoneal layer), thus placing the bile duct into a deeper and more cranial layer of the triangle. When these ducts are severed the result can be obstructive segmental cholangitis, hepatic abscess, prolonged biliary fistula or bile peritonitis (14). If the diameter of the duct is 4 mm or larger it is likely to drain entire segments or the right liver lobe. On the other hand, ducts smaller than 3 mm can be safely ligated if cholangiography demonstrates filling of a single segment (17). Our results have quantified the sectoral bile ducts as smaller than 3 mm in caliber. However, they should be carefully ligated if severed, in order to prevent the previously mentioned complications. Because the sectoral bile ducts are the only drainage path for a segment of the liver these injuries are difficult to diagnose. ERCP will not visualize the duct, resulting in a cholangiogram which is interpreted as normal.

Conversions in MIS gallbladder surgery are reported to occur in 0.42-6 % cases (75). The largest number of conversions (58.9%) was attributed to situations when the anatomy was unclear, due to adhesions, inflammation, poor visualization or suspicion of aberrant anatomy (84). Intraoperative bleeding was the reason in 9.8% while bile duct injury or abnormal cholangiography was the reason for conversion in 4.4%. More recent articles on the subject show that unclear anatomy is the main reason for conversion in most cases (50-70%) followed by intraoperative bleedings (14-15%) and suspected bile duct injury (1-8 %) (85, 86). These data do not clarify if the bleeding precedes bile duct injury, is it vice versa, or do these adverse events occur independently. There are some data in the literature that suggest a link between injuries of the right hepatic artery and CBD (83, 87, 88). It has been suggested that an important mechanism in the occurrence of major bile duct injury is when intraoperative bleedings prompt initial attempts to control the bleeding by the “blind” placement of multiple clips. Despite the obscurity of the data in the literature it has been suggested that 2/3 of the MIS bile duct injuries occur through this mechanism.

When performing MIS cholecystectomy the surgeon expects to find a single cystic artery within Calot’s triangle. Our data suggest that multiple arteries occur in 15.7 % specimens. An important fact is that the position of the cystic artery can be occupied by the right hepatic artery (caterpillar hump in 12.9%) or by the two segmental liver arteries originating from the right hepatic (8.6 %). In both these cases the cystic artery is extremely short, originating from the right hepatic artery or one of its segmental branches, thus rendering the larger arteries susceptible to injury. Furthermore, our results show that the second cystic artery is smaller in caliber but often better hidden than the first and of much shorter length. In 60% specimens it approaches the gallbladder outside Calot’s triangle, most often through the hepatic tissue, causing troublesome bleedings if severed. The technique of limited dissection (66, 80) as well as adequate cognitive skills will allow for the preservation of the hepatic vessels and the

correct identification of the cystic arteries, preventing arterial bleedings that can lead to further injuries. Arteries run superficially in the triangle of Calot, and perpendicular to the CBD.

The last and most infrequent combination is when an artery is not encountered within Calot's triangle. One should at first attempt to find it posterior and lateral to the cystic duct (1.4 %), originating from the gastroduodenal artery (67), and this being the only case when the artery is not found superficially under the peritoneum. If not found there it is to be found in the most cranial part of Calot's triangle, reaching the liver bed and giving multiple branches that irrigate the gallbladder (4 %). This configuration can give troublesome bleedings during or after the MIS procedure.

Recent literature shows that arterial bleedings from the liver bed occur and cause conversion more often than previously reported (0.09-1.3 % vs 8-9 %), and that these can be the cause of lethal outcome (20, 84, 86). When the cause for these arterial bleedings is not in the second cystic artery, or an atypical cystic artery in the most cranial segment of Calot's triangle, one should suspect an arterial anastomosis between the cystic artery and hepatic artery system (12 % specimens). These arterial anastomoses bleed from both ends and are located in the liver bed. Bleeding can often occur after the surgical procedure is finished if thermocautery or ultrasound were used for their division. Some published case reports of postoperative bleedings from the gallbladder bed find other less probable reasons for the bleedings such the use of NSAIDS (89), which can in turn only facilitate such bleedings but cannot be their cause. The fact that the origin of the bleeding is not found at reoperation is a consequence of compression by the growing blood clot. An occasional lateral branch of the cystic artery irrigates a small area of the anterior liver lobe and is not of significance in MIS cholecystectomy other than arousing the surgeon's suspicion and prolonging the procedure.

A vein of significant diameter under the lateral peritoneum of Calot's triangle occurs in 4% specimens. It is the deepest anatomical structure of the triangle and located in its cranial segment, and drains directly into the portal vein or its right branch. If it is of large caliber (1.6 mm) it should be separately ligated.

#### **5.4. Anatomical considerations after spleen injury during left colectomy**

When spleen injury occurs during left colectomy, surgeons prefer splenectomy because it is a quick and effective solution to a serious problem that has an otherwise unpredictable outcome. The soft consistency and high blood perfusion of the spleen are reasons enough to consider operating within the spleen hilum hazardous. The presumed unimportance of the organ facilitated decision making. The more recently recognized immunological deficits resulting from splenectomy have caused a change in the surgeon's attitude towards the spleen and splenectomy (90, 91). In open surgery, between 21-40% of spleens removed are healthy spleens that have this fate due to iatrogeny (92, 93). In almost all patients, spleen injury consists of a capsular tear and is a result of traction on spleno-omental bands in 50% (94). Open left hemicolectomy bears a high risk to healthy spleens (1-15%), as do funduplications and left nephrectomy (94, 95). It is improbable that another healthy organ has been completely removed more often than a healthy spleen.

When MIS procedures are concerned iatrogenic spleen lesion seems to occur less frequently. An extensive search of the MEDLINE database for iatrogenic/intraoperative spleen injury within laparoscopic colon resection yielded only two references, a capsular tear of the inferior splenic pole (96) and an undescribed spleen lesion (97). Another similar injury was reported during MIS Heller myotomy for achalasia (98). Furthermore, both these spleen injuries, in contrast to open surgery, did not result in splenectomy. The reasons for this discrepancy can

lie in the specifics of MIS (magnification, better overview, instruments that cause lesser trauma, less traction to the splenic ligaments) but can also be the result of underreporting. Our studies have identified the arterial vessels of the splenic hilum as vessels that can be surgically accessed. Arteries lie anterior to the veins within the splenic hilum. Furthermore, data on the intra-parenchymal and extra-parenchymal intersegmental anastomoses can provide a rationale for the absence of necrosis in most of the dearterialized spleens. Total or partial dearterialization of the spleen can be performed with an uneventful outcome (95, 99,100), providing the venous drainage paths are preserved. Proof of the adequate function of the dearterialized organ has been provided (101, 102). Dearterialization of a splenic lobe/segment represents a first step in partial resection of the spleen. Spleen lobe/segment dearterialization renders splenic resection obsolete if the spleen is healthy. Laparoscopic partial resection of the spleen has its indications when pathology exists within the splenic tissue (103, 104), and can be burdened with a higher risk for postoperative bleeding.

### **5.5. Anatomical considerations in complications during/after right colectomy for cancer.**

Conversions within MIS colorectal surgery are reported to occur in 2-77 % cases (105). The data on right colectomy are not readily accessible; however conversion seems to occur more seldom during right colectomy (between 9.0-21%) than in other colorectal procedures (105-109). In addition, some of these studies have demonstrated that a reduction in conversion rates correlates with growing surgeon's experience, but have failed to demonstrate a reduction in postoperative complication and 30-day readmission rates. Reasons stated for conversion are unclear anatomy, intra-operative complications, hemorrhage, perforation, adhesions, obesity and equipment failure (110). Despite the fact that hemorrhage is cited as a frequent reason for conversion, it is only seldom that the origin of this bleeding is reported, and when it is, it is

described in vague terms. Bleeding is the reason for conversion in 7.1-30,9 % of all conversions in MIS colorectal surgery (27, 107, 109, 111, 112), while bleeding from the mesocolonic vessels seems to account for at least one half of the cases (111, 112). Excessive traction of the bowel is reported to cause both enterotomy and bleeding (27, 107, 111, 112). Our study shows that the position of the GTH is favorable for traction avulsion injuries, if the bowel is drawn in a ventral-cranial direction and provides anatomical data pertinent to how this bleeding can be controlled. The fact that there is no artery accompanying the gastro-colic trunk of Henle represents another major danger, and that is failure in recognizing the trunk and injuring it (113). CT or MRI, particularly thin section 3-D contrast enhanced dynamic fat-suppressed imaging, can provide valuable data on the GTH prior to surgery (114).

All colon resections require mobilization and devascularization of the colon and its mesentery, whether performed by a conventional or MIS approach. Most surgeons performing MIS colectomy proceed with colonic mobilization and vascular pedicle ligation intracorporeally, whereas some surgeons complete only colonic mobilization laparoscopically, and then perform the remainder of the procedure extracorporeally.

Whichever method is used, the extent of lymph node dissection performed laparoscopically should be no less than the extent of dissection which is routinely carried out in standard laparotomy for colonic carcinoma (115). Lymphatic drainage of the colon runs along the vasa recta and marginal arteries, forming larger channels before they enter the paracolic nodes. The lymphatic vessels then reach the intermediate and main nodes following the main trunk arteries (ICA, RCA). Some authors have reported that the course of the lymphatics runs along the anterior aspect of the superior mesenteric mesentery, which means under the parietal peritoneum (115-7). Our study shows that the ICA crosses posterior to the SMV in 66,3% of the specimens and that the RCA has the same path in 16% specimens. This may suggest that the course of the lymph vessels following the ICA and RCA artery would lie on the posterior

aspect of the superior mesenteric mesentery. The anterior aspect of the superior mesenteric mesentery is a well defined layer because it is covered by peritoneum, while its posterior aspect is not a clearly defined surface, depending on the surgical technique applied during mobilization of the right colon.

It has up to date been confirmed by a large number of studies that MIS surgery does not change the principles of oncologic surgery: en bloc resection, no-touch isolation technique, proximal lymph vascular ligation, complete lymphadenectomy, wound protection and adequate margin of resection (118). However, descriptions of the extent of lymphadenectomy and mesenteric resection are vague, and there is no uniform rule for lymphadenectomy (119). Both the number of lymph nodes harvested and the level of ligation of the mesenteric vessels have been used to evaluate of the extent of lymphadenectomy (115, 119).

While operative reports usually state that the ICA and RCA are ligated at the origin from the superior mesenteric artery, what in fact is done in most cases is ligation at the right hand side of the SMV. A search of the literature has provided no references for ligature of the ICA or RCA posterior to the SMV, while only anterior ligation has been reported in large series of patients (115). The results of our study imply an arterial stump (17mm ICA and 20 mm RCA) after the procedure. Nevertheless, it is difficult to recommend routine dissection of the arteries to their origin in order to remove all lymph nodes, since operating under the SMV could be hazardous, especially in case of MIS. However, it can be recommended in cases when the arteries run anterior to the vein.

## **6. Conclusion**

Based on the results of the studies included in the present thesis, we can conclude:

### **Segment 1. MIS gallbladder surgery**

Third structures within Calot's triangle that can cause complications during/after laparoscopic cholecystectomy were arteries in 36.2%, bile ducts in 5.7% and veins in 4% of specimens.

When bile ducts are concerned the following variants were identified and quantified:

- sectoral bile ducts (5.7%), of these:
  - small-caliber sectoral ducts (1.4%)
  - right posterior hepatic ducts (4.3%)

When arteries are concerned the following variants were identified and quantified:

- early division of the right hepatic artery (8.6%)
- caterpillar hump right hepatic artery (12.9%)
- liver branch of the cystic artery (10%)
- double cystic arteries (14.3%)
- second cystic artery is most often atypical in course (60%)

Bleeding from the gallbladder bed during and/or after laparoscopic cholecystectomy can occur due to the presence of:

- anastomoses between the cystic artery and hepatic arteries (12%)
- an atypical cystic artery located in the most proximal segment of Calot's triangle, giving rise to 5-7 radial branches to the gallbladder within the gallbladder bed (4%)
- a second cystic artery approaching the gallbladder through hepatic tissue

Gallbladder veins of significant caliber joining the portal vein were found and quantified in 4% of specimens.

## **Segment 2. Spleen injury in left colectomy**

Anatomical considerations pertinent to splenic conservation after intraoperative injury are:

- the mean inferior terminal splenic artery had a significantly smaller diameter than the superior (2.8 vs. 3.4 mm,  $p < 0.01$ )



- the superior terminal branch divided extracapsularly into 2.8 (range 2-5) branches
- the inferior terminal branch divided extracapsularly into 2.3 (range 2-5) branches
- extracapsular lengths of segmental branches ranged from 4.0 to 16.7 mm and the calibers from 0.4 to 2.2 mm
- An inferior polar artery was found in 22.5% of the specimens (mean diameter, 1.9; mean length, 33 mm).
- Superior polar arteries occurred in 31.3% (mean diameter, 2.5; mean length, 39 mm).
- The inferior lobe and inferior polar segment comprised 41.3% and 12.6% of the spleen, respectively.
- Anastomoses were detected in 34 of 102 spleens (3% extraparenchymal, 88% intraparenchymal, 9% combined).
- The mean diameter and length of intrasplenic anastomoses were 0.3 and 20 mm, respectively.

Segmental splenic and polar arteries have an extrasplenic origin and course, with an average length and caliber that allow surgical access. Intrapasplenic anastomoses can be the basis for absence of necrosis after dearterialization.

### **Segment 3. Vascular complications in right colectomy.**

The 3-D anatomical relations of interest in right colectomy are:

- GTH was present in all specimens
- GTH originates from the confluence of the right gastroepiploic and superior-anterior pancreaticoduodenal veins.
- GTH joined the SMV at an average distance of 2.2 (1.6-3.2 ) cm from the inferior pancreatic border

- its course is towards the right side in a ventral-cranial direction, and therefore traction in this direction can result in its injury
- mean caliber and length of the GTH were 5.2 (4.8-5.8 ) and 16.1 (10.1-20.7) mm, respectively
- ICA was present in all specimens
  - ICA crossed posterior to SMV in 19/30 specimens (63.33%)
  - Length of crossing was 17.0 (7.1-42.9) mm
- RCA was present in 19/30 specimens (63.3%)
  - RCA crossed anterior to SMV in 16/19 specimens (84.2%)
  - Length of crossing was 20.6 (6.3-35.7) mm

These results have an impact how to prevent bleedings due to traction injury and on the extent and thoroughness of lymphadenectomy within right colectomy for cancer.

With these results in mind we can state that the corrosion cast model provides vital 3-D anatomical data to surgeons operating in a 2-D environment and that these data can, in turn, provide a rationale for some of the complications that occur during/after MIS procedures.

MIS procedures are a high-risk system, and as most high-risk systems it has some special characteristics that make accidents in them inevitable, even normal. With the use of this 3-D anatomical model it is possible to analyze and gain much better understanding of why these complications occur. The data obtained in these studies sheds light on the misperception errors in MIS; however these errors do not meet the criteria of medical negligence because of the nature of human cognition.

The surgical community has now arrived at a point when outcomes of care studies in MIS have provided initial data on the surgeon's performance, and these have shown a threefold rise in complication rates. A "quality of care" evaluation is needed (120). These entail a systematic analysis in the process of care, in this case how individual MIS surgeons are

systematic analysis in the process of care, in this case how individual MIS surgeons are sculpted, and how we can improve the process. Furthermore, the process change through the introduction of MIS has not resulted in a change in the way anatomy is taught in medical schools. It is our opinion that the systems of surgical practice can be remedied to combat errors through the direct involvement of 3-D anatomy and laparoscopic surgeons in the teaching process. Hopefully, this can lower complication rates to under those prior to the introduction of MIS.

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